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A COMPUTER PROGRAM INCORPORATING FATIGUE AND FRACTURE CRITERIA IN THE PRELIMINARY DESIGN OF TRANSPORT AIRCRAFT: AN EVALUATION

By

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Principal Investigator: Earl A. Thornton

Prepared for the
National Aeronautics and Space Administration
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Final Report of Supplement Task A Under
Grant NSG 1093 (Thermal Structural Analysis of SCRAMJET Structures)
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A.R. Wieting, Technical Monitor
H.A. Leybold, Technical Monitor for Supplement Task A
Materials Division

Submitted by the
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Norfolk, Virginia 23665

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INTRODUCTION

The author has been engaged with familiarization and debugging of the APAS (Automated Pre-design of Aircraft Structures) computer program from December 1974 to July 1975. The program was developed for NASA under contract (see ref.) as part of a large computer program to assess the impact of fatigue and fracture criteria on the weight and cost of transport aircraft. The program options were exercised on two transport wings to determine the program's capability to design optimum weight structure which meets both static strength and fatigue strength requirements.

The APAS Program

The APAS program is a multi-station structural synthesis procedure developed to evaluate material, geometry and configuration with various design criteria usually considered for primary structure of transport aircraft. The program contains a built-in load spectrum, material properties for nine metals and two composites, fatigue S-N data, fatigue damage criterion, and fracture mechanics criteria. Minimum user inputs required are: loading conditions, initial and maximum material gages, construction type, and number of stations along the structure to be analyzed. Fatigue life and fail-safe strength are also required by the program if the user wishes to include fatigue, flaw-growth, or residual strength (fail-safe) analyses. The user may exercise the option to input his own material (one metal or one composite), fatigue data, or fracture mechanics criteria simply as additional data without altering the program itself.

The existing program optimizes the cross section (minimizes weight) of a single-material box beam. The user inputs the initial geometry of the cross section and the program sizes the cross section to produce minimum gages which satisfy the stress allowables. Then, a modified Fletcher-Powell-Davidon non-linear programming technique is used to minimize the stress in each element while holding the weight (area) constant. The cross section is then resized to produce minimum material gages. This process is continued station by station until the entire structure has been sized to meet static strength requirements. The structure is then resized to meet fatigue and fracture criteria if this option has been selected. The entire process is iterated until the design converges, convergence being defined as two successive iterations producing a change in weight that is within a specified tolerance. If the user has chosen not to analyze each station along the structure, the program automatically uses a non-linear interpolation routine to estimate the weight between stations analyzed. A functional flow diagram of the program is shown in figure 1.

The monolithic, riveted, or bonded construction types shown in figure 2 are available as design options. Material selection includes aluminum, titanium, Inconel, boron-epoxy, and graphite-epoxy. The S-N data for these materials are built into the program and are derived from actual component data or are based on coupon data where component data were unavailable.

The flight profile and load spectrum incorporated in APAS is typical of that used for fatigue and flaw growth analysis of transport aircraft. The flight load spectrum is composed of the following loading conditions: 1G taxi, 1G level flight, 2G vertical gust, 2G maneuver, 1G landing impact, maximum cabin pressure, and the ground-air-ground (GAG) cycle. The

frequency of occurrance of the loads is based on data derived from 10,000 flights of a typical transport aircraft.

Miner's linear cumulative damage rule is used as the basis for estimating cumulative fatigue damage per flight over the life of the aircraft. The procedure is well known and generally accepted for its analytical simplicity.

A conservative flaw growth analysis based on the Erdogan growth rate equation is performed to determine crack-growth lives for stiffened panels under the influence of a fatigue load spectrum. The method is conservative in that flaw growth retardation effects due to spectrum loading are not included, however, a crack-growth retardation analysis could be added to the program. The initial crack size and number of broken stringers for the analysis can be varied. Integrally stiffened panels are treated as unstiffened sheets with areas equal to the stiffened panels.

The program performs a residual strength analysis to determine the failing strength of a stiffened panel consisting of skin cracks and broken stiffeners. Unstable crack growth is assumed to occur when the stress intensity factor exceeds the fracture toughness of the material. When the stress level of the most highly loaded stiffener exceeds its ultimate tensile strength, the program assumes failure of the stiffener and recalculates stress intensity factors of the skin to reflect this condition.

Program Evaluation

Two transport wings selected from existing conventional transports (Convair 880 and DC 10) were used as inputs to test the accuracy and function of the program. Here two problems were noted. First, the resultant optimum weight can vary with the number of cross sections synthesized along the structure. While this procedure of analyzing some of the stations and interpolating between the remaining stations to estimate the structural weight is efficient in terms of reduced execution time and computer cost, the user must exercise experience and sound judgment based on the configuration of the aircraft and the load distribution to obtain reasonably accurate estimates. Second, performance of the program in terms of predicted weight relative to actual design weight is generally good and the solutions converge toward minimum weight if the structure is composed of a single material where E/ρ is constant. However, the optimization process becomes divergent if E/ρ is not constant, therefore minimum weight may not be found for multi-material structures.

Recommendations

The program, which is debugged and operational, can be used to assist in the preliminary design of single-material, metal primary aircraft structures. The following are recommendations to improve accuracy and extend the capabilities of the APAS program.

1) APAS should be modified to analyze multi-material structures where E/ρ is variable and analysis of composite materials should be improved.

2) The non-linear interpolation routine should be modified or replaced by a linear interpolation scheme to reduce the effects of the number of stations analyzed.

3) The present version of the program treats through cracks only. Flaw types such as part-through cracks, cracks starting from holes, and corner cracks should be added in addition to crack-growth retardation. It is necessary to make these additions since the flaw types mentioned occur frequently in aircraft structures and are included in damage tolerance criteria for new aircraft. The addition of a crack-growth retardation scheme would provide better accuracy.

4) The built-in data for the load spectrum should be replaced by a load spectrum input option.

REFERENCE

Tanner, C. J.; Kruse, G. S.; and Oman, B. H.: Computer Program to Assess Impact of Fatigue and Fracture Criteria on Weight and Cost of Transport Aircraft. NASA CR-132648, June 1975. General Dynamics Convair Division Contract NAS1-12506.

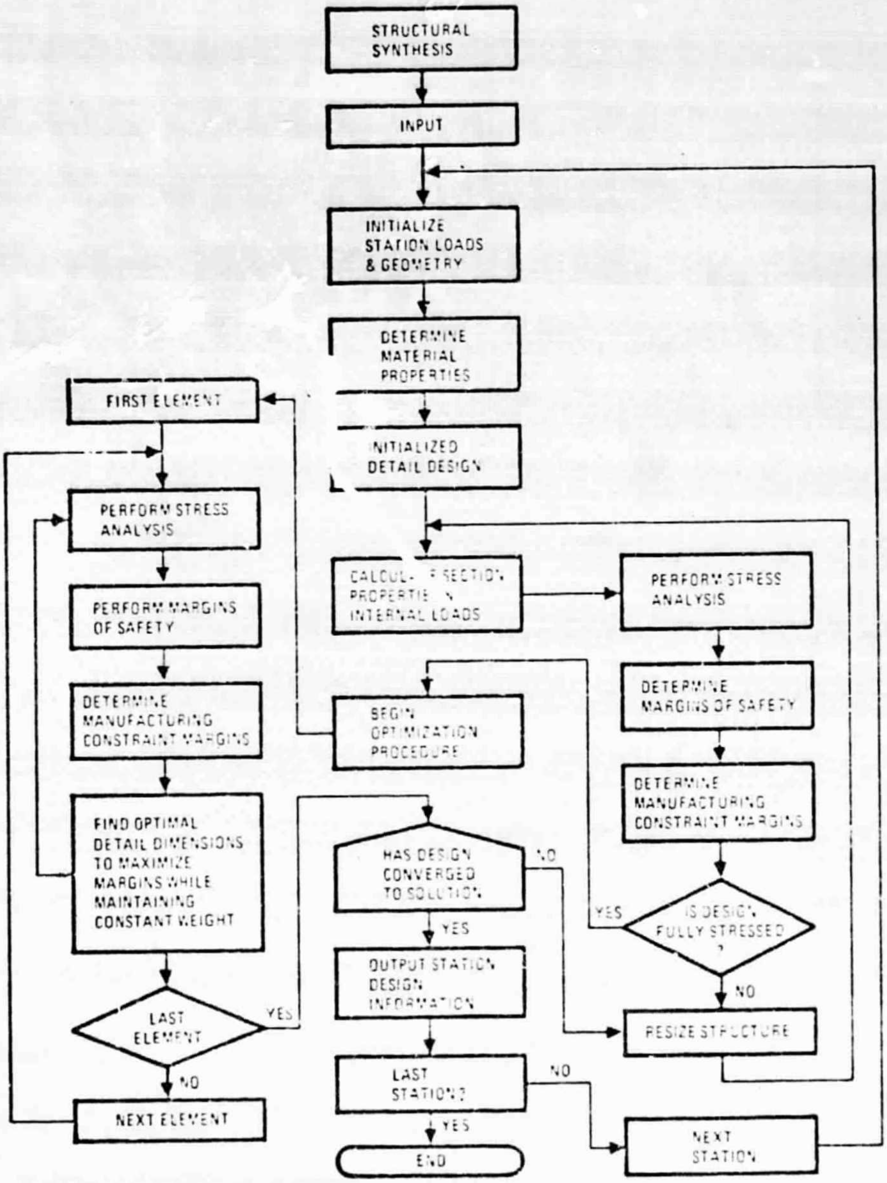

Figure 1. APAS Flow Diagram

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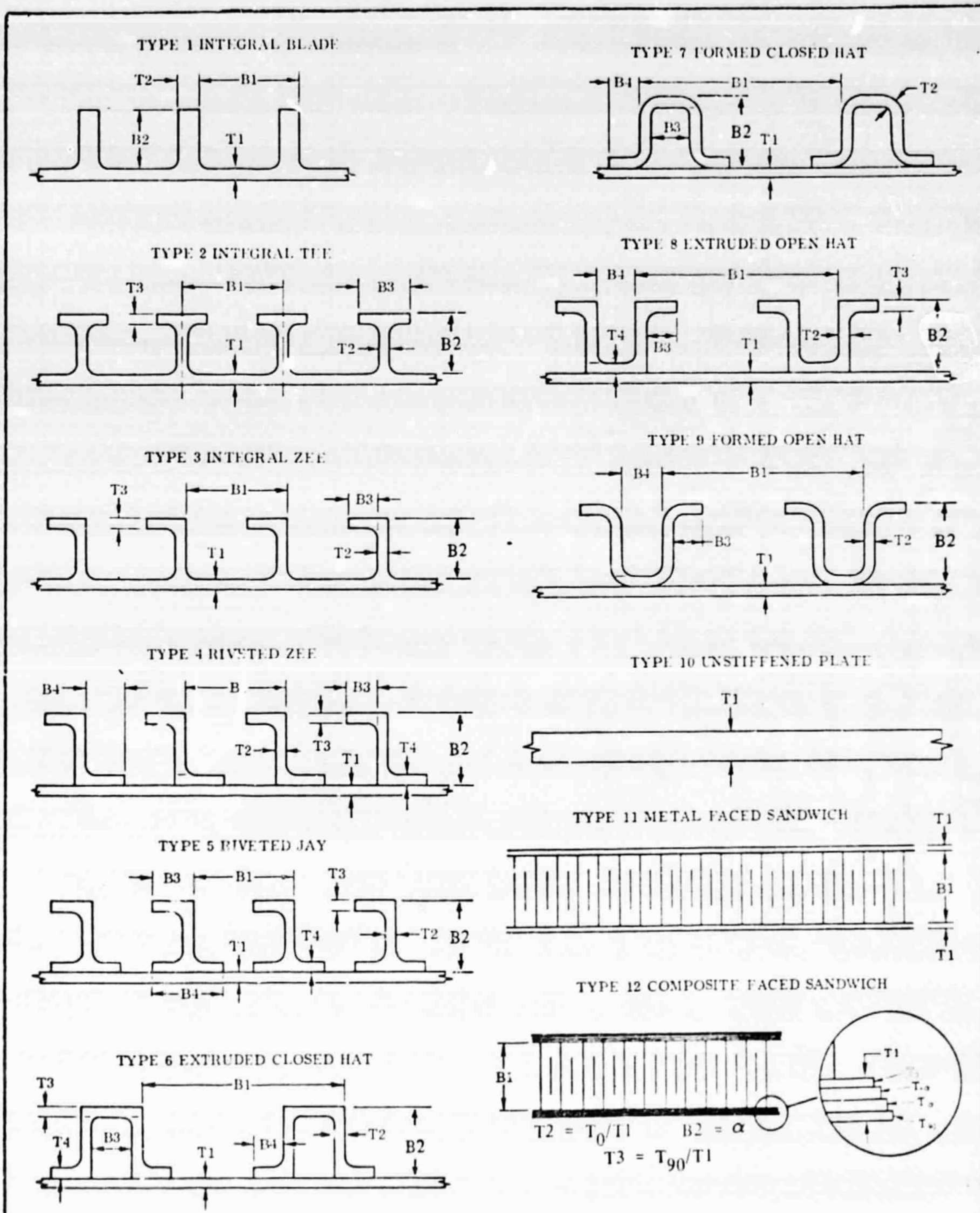

Figure 2(a). Skin Panel Elements

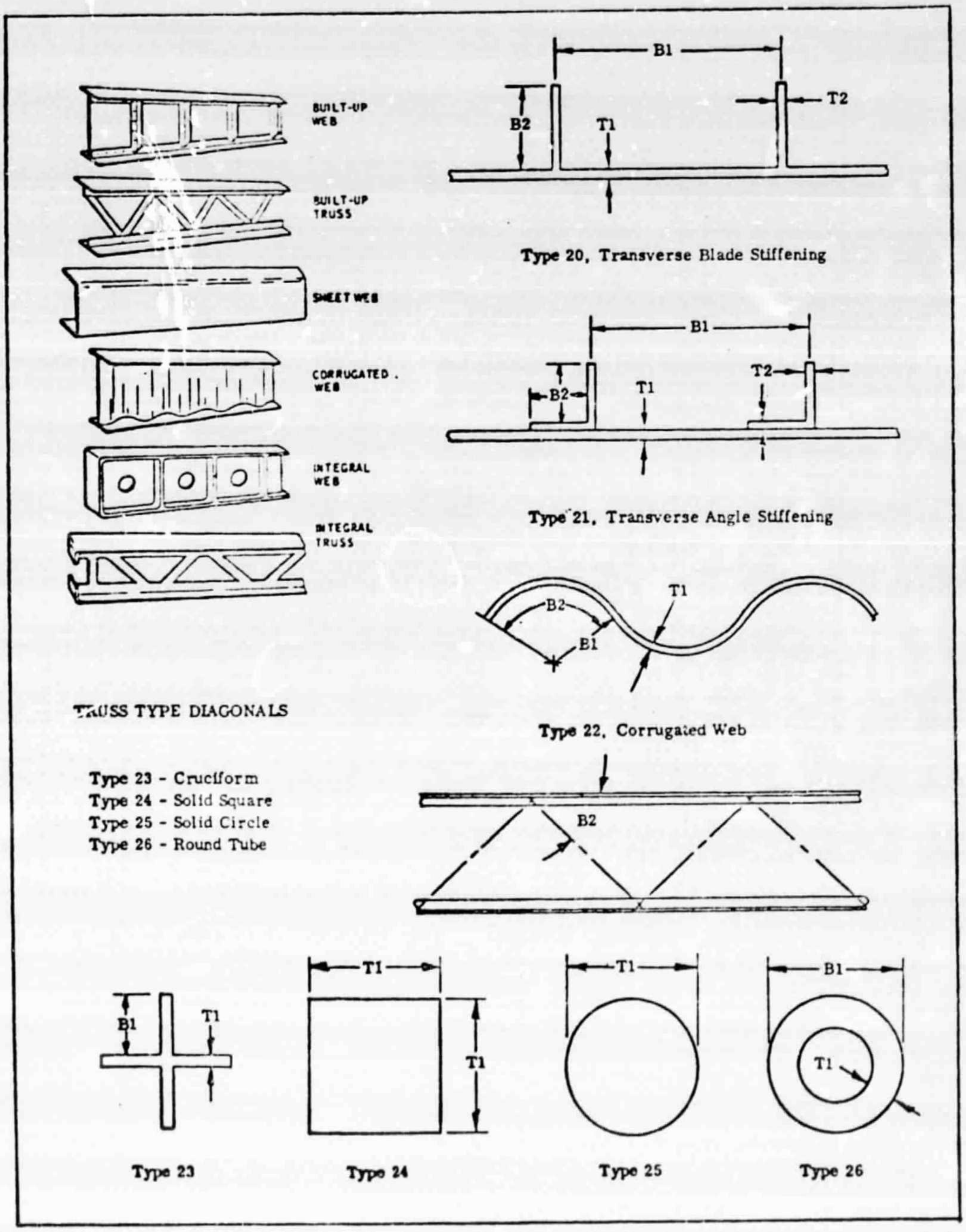

Figure 2(b). Spar Web Elements

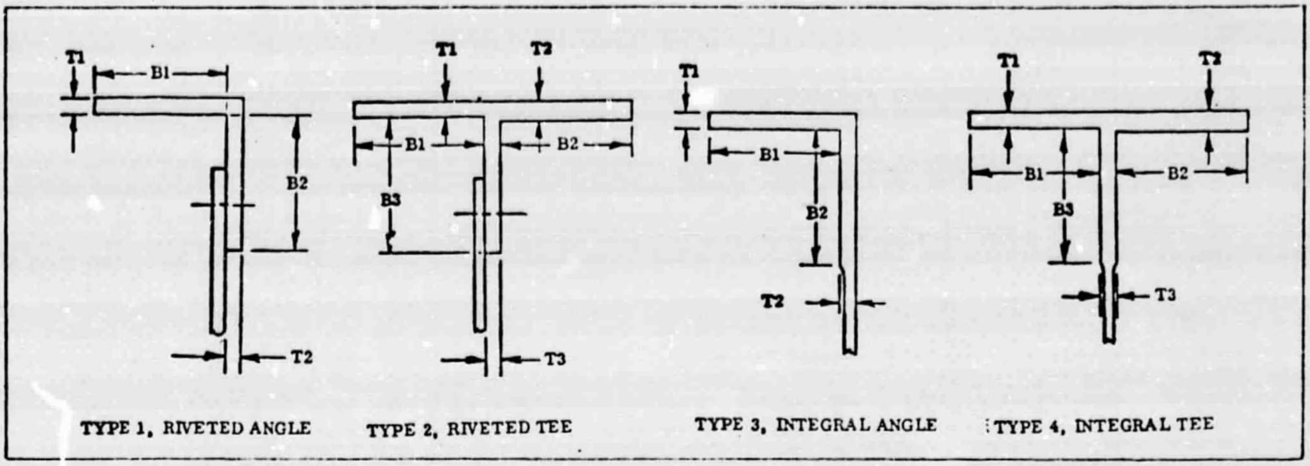

Figure 2(c). Spar Cap Elements

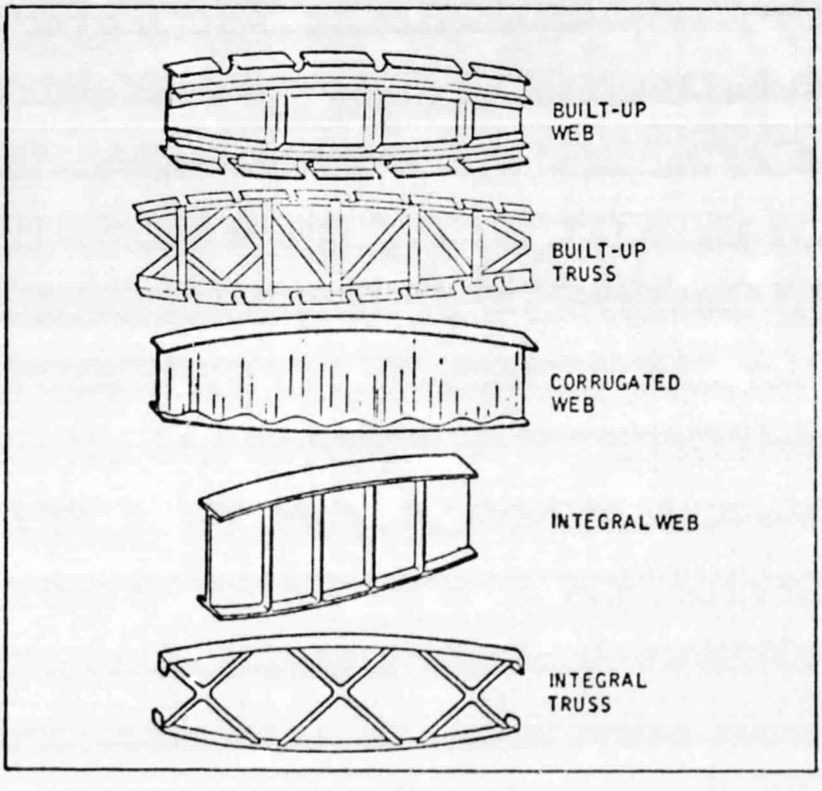

Figure 2(d). Ribs

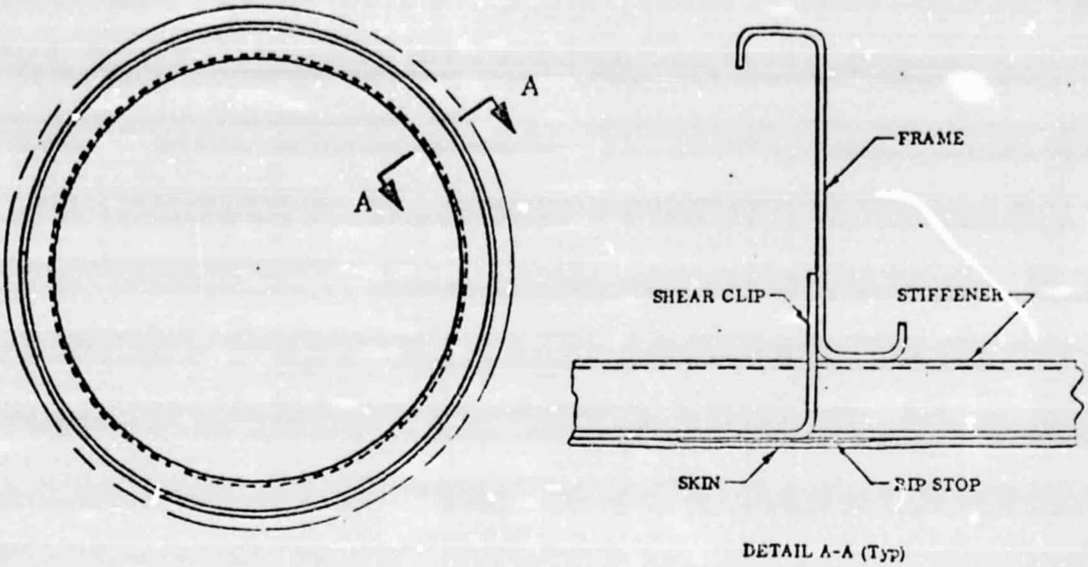

Figure 2(e). Typical Ring Frame